Clinical Infectious Diseases

MAJOR ARTICLE

Pneumococcal Conjugate Vaccines Turning the Tide on Inequity: A Retrospective Cohort Study of New Zealand Children Born 2006–2015

Helen Petousis-Harris,[1] Anna S. Howe,[1] Janine Paynter,[1] Nikki Turner,[1] and Jennifer Griffin[2]

[1]Department of General Practice and Primary Health Care, Faculty of Medicine and Health Science, University of Auckland, New Zealand; and [2]RTI International, Berkeley, CA

Background. Hospitalization rates for infectious diseases in New Zealand (NZ) children have increased since 1989. The highest burden is among Māori and Pacific children, and the most socioeconomically deprived. New Zealand introduced pneumococcal conjugate vaccine (PCV)7 in June 2008, PCV10 in 2011, and PCV13 in 2014.

Methods. A retrospective cohort study of NZ children aged <6 years between 2006 and 2015 was performed using administrative databases. Demographics and hospitalizations were linked to evaluate the impact of the PCV vaccination program on cases of invasive pneumococcal disease (IPD), all-cause pneumonia (ACP), and otitis media (OM), defined by ICD-10-AM codes, and to explore the effect by ethnicity and deprivation.

Results. Between 2006 and 2015, there were 640 children hospitalized with IPD, 26 589 for ACP, and 44 545 for OM. IPD hospitalizations declined by 73% between 2005 and 2015 for children <6 years of age, whereas ACP and OM declined by 8% and 25%, respectively. The highest rates for all diseases were among Māori and Pacific children and those from high deprivation. However, the declines were highest among Māori and Pacific children and those from socioeconomically deprived areas. IPD hospitalizations declined by 79% and 67% for Māori and Pacific children, respectively, between 2006 and 2015. ACP declined by 12% in Māori and 21% in Pacific children. OM declined by 51% in Māori children.

Conclusion. In contrast to the increasing trend of hospitalization rates for infectious disease in New Zealand, the use of PCV appears associated with reductions in ethnic and socioeconomic disparities in hospitalization for IPD, ACP, and OM.

Keywords. pneumococcal conjugate vaccines; invasive pneumococcal disease; pneumonia; otitis media; ethnicity.

Since 1989, New Zealand's (NZ) hospital admissions for infectious diseases in children under 5 years of age increased by 22%, peaking in the 1999–2003 period. The most dramatic increases were in the indigenous Māori population (27.6%) and Pacific Island children (48.3%), with ratios more than twice that of the New Zealand European population. In contrast, hospitalizations for noninfectious diseases declined for all ethnicities in this period. Contributing to this increase are upper respiratory tract infections, including ear infections (+6.3%) and lower respiratory tract infections (+66.2%). Most notable has been the overall increase in both socioeconomic and ethnic inequalities over time, particularly among children under 5 years of age [1].

New Zealand introduced pneumococcal conjugate vaccine (PCV)7 in June 2008 in a 3 + 1 schedule (6 weeks, 3 months, 5 months, and 15 months), PCV10 in 2011, and PCV13 in 2014. Since then, there have been reductions in the rates of invasive pneumococcal disease (IPD) attributed to PCV vaccine types almost to the point of elimination in the vaccine-eligible age group [2]. This has been the case worldwide with an estimated reduction in incidence of IPD ranging from 79% to 100% after PCV7 introduction [3]. Very few studies have examined differences in rates by ethnicity or socioeconomic status [4–7].

The objectives for this study were to collate and analyze annual hospital admissions for IPD, all-cause pneumonia, and all-cause otitis media (OM) for NZ children under 6 years of age from 2006 to 2015 by age group, ethnicity, geographical area, and socioeconomic deprivation. We present the impact of the introduction and routine use of PCV7 and PCV10 on the incidence of IPD, all-cause pneumonia, and OM hospitalizations.

METHODS

This was a retrospective national cohort study. The study population was all NZ children less than 6 years of age between 1 January 2006 and 31 December 2015 (Figure 1). Although we have not determined immunization status of the children included in the study, NZ immunization coverage data for the year ending 2015 indicates that coverage was 83%. Coverage for

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Correspondence: H. Petousis-Harris, Department of General Practice and Primary Health Care, School of Population Health, Faculty of Medicine & Health Science, University of Auckland, New Zealand (h.petousis-harris@auckland.ac.nz).

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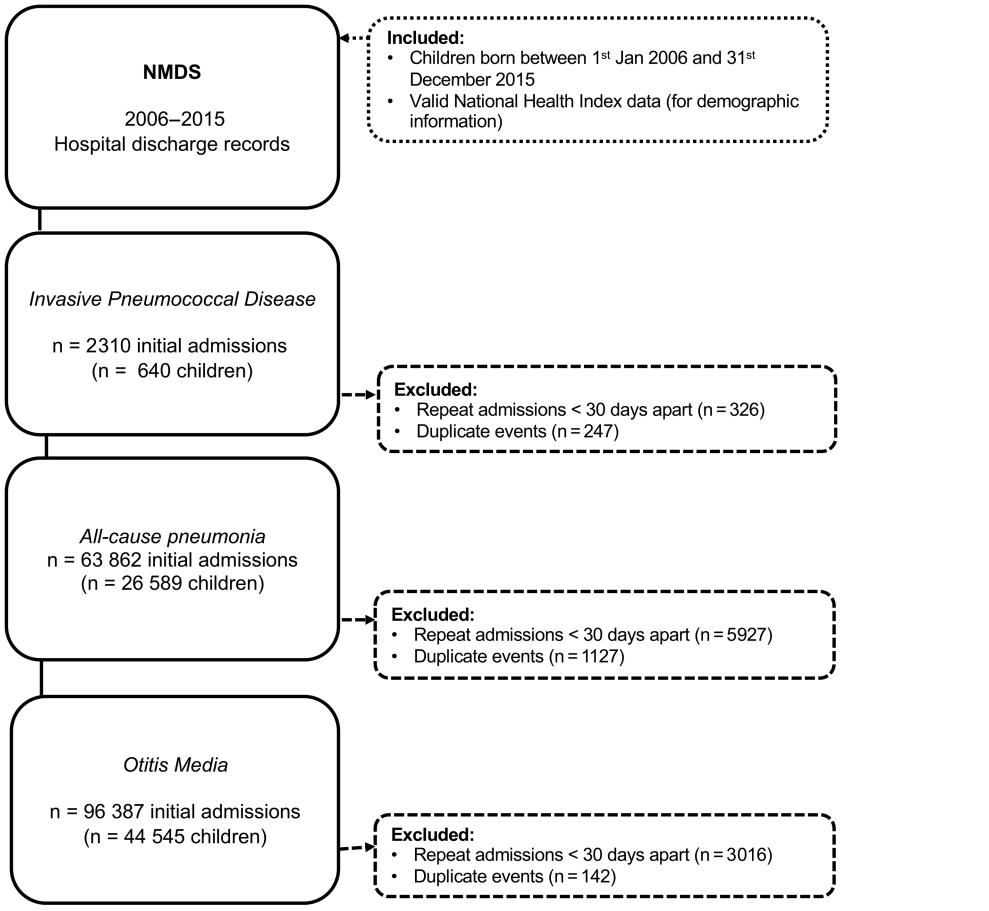

Figure 1. Flow chart of hospitalizations [1]. Abbreviation: NMDS, National Minimum Data Set.

Māori and Pacific Island individuals was slightly lower, 81% and 79%, respectively [8].

Analyses utilized the following data sources:

National Health Index (NHI) Database contains demographic information for all people born in New Zealand and for people born outside of New Zealand who access the healthcare system (note: the NHI database includes records for travelers and other people who do not live in New Zealand). A person's NHI number, date of birth, date of death, and sex are static; however, the remaining data fields may change over time. Data fields relevant to this study include NHI (encrypted), date of birth, date of death, sex, prioritized ethnicity (Māori, Pacific, Asian, New Zealand European, and Other), geographic area of residence (district health board), and socioeconomic deprivation level (NZ Deprivation Index 13).

National Minimum Data Set (NMDS) is a national collection of public and private hospital discharge information since 1988, including coded clinical data. New Zealand has 20 district health boards for funding, planning, and providing health services. Health services in New Zealand are funded by the government, and as such, eligible persons receive free inpatient and outpatient public hospital services. The NMDS is used for policy formation, performance monitoring, research, and review. It provides statistical information, reports, and analyses about the trends in the delivery of hospital inpatient and day-patient health services both nationally and on a provider basis. It is also used for funding purposes. Data fields relevant to this study include NHI (encrypted), admission event ID, admission date, discharge date, and ICD-10-AM diagnosis code (the primary plus up to 99 diagnosis codes are available for each admission event).

IPD, all-cause pneumonia, and OM hospitalizations were defined using specific ICD-10-AM codes listed in the 100 available diagnosis fields of the NMDS. Repeat hospitalizations (ie, hospitalizations for a single child that occurred within 30 days of a previous hospitalization for the same condition) were deleted.

ICD-10-AM codes used to define IPD were G001, G002 + B953, G002 + A403, and G002 + A491 + B953, J13, A403, A419 + B953, A409 + B953, A499 + B953, R509 + B953, R560 + B953, M001, M009 + B953, K650 + B953, K659 + B953, J86 + B953, and M8600-M8699 + B953. Codes for all-cause pneumonia were J12-J18, J10.0, and J11.0. Codes for OM-associated hospitalizations were H65, H66, H67, H70, H74, H75, H92, Australian Classification of Health Intervention codes 41632-00 myringotomy with insertion of tube, unilateral, and 41632-01 myringotomy with insertion of tube, bilateral.

Age of hospitalization was determined from the NHI date of birth and NMDS date of admission. Ethnicity categorizations were based on groupings of prioritized ethnicity codes [9]. Socioeconomic deprivation was measured by the NZDep2013 Index, which was matched at the level of children's census area unit of residence. The NZ Deprivation Index is a measure of socioeconomic status with 10 being the highest level of deprivation of 10% of the population and 1 being the lowest level of deprivation of 10% of the population [10].

Statistical Analysis

For descriptive analyses, person-years were based on the number of children less than 6 years of age counted during the 2006 and 2013 NZ censuses. The NZ census data are based on the usual resident population. Person-years for intercensus years (2007–2012 and 2014–2015) were extrapolated by assuming a linear increase in the number of children between 2006 and 2013. Unadjusted rates were calculated as the number of events divided by the sum of person-time and reported per 100 000 person-years. Linear trends were tested using Cochrane-Armitage trend tests for changes over time, age, and deprivation, with the highest *P* value reported for subgroup analyses. The χ^2 tests were used to examine differences between ethnicity and region. Percentage change was calculated as the difference between number of hospitalizations between 2015 and 2006, unless otherwise stated.

RESULTS

In New Zealand, there were 344 020 and 375 720 children younger than 6 years of age counted during the 2006 and 2013 censuses, respectively.

Invasive Pneumococcal Disease

There were 640 children less than 6 years of age hospitalized for IPD between 2006 and 2015 (Table 1). All children hospitalized for IPD had a single admission except for 8 children who were admitted twice and 1 child who was admitted 5 times. Median age at first hospitalization was 17.8 months (interquartile range [IQR]: 9.3, 35.8). During the 10-year period, there was a statistically significant decrease in the rate of initial IPD hospitalizations among children less than 6 years of age, from 26.45 per 100 000 person-years in 2006 to 6.50 per 100 000 person-years in 2015 ($P < .001$)

Table 1. Rates of Initial Invasive Pneumococcal Disease Hospitalization Among Children Less Than 6 Years of Age From 2006 to 2015 (Inclusive)

	N	Person-Years[a]	Rate[b]	(95% CI)	*P*[c]
Calendar year					
2006	91	334 020	26.45	(21.02, 31.89)	
2007	104	348 548	29.84	(24.10, 35.57)	
2008	101	353 077	28.61	(23.03, 34.18)	
2009	88	357 605	24.61	(19.47, 29.75)	
2010	45	362 135	12.43	(8.80, 16.06)	
2011	51	366 663	13.91	(10.09, 17.73)	
2012	52	371 192	14.01	(10.20, 17.82)	
2013	41	375 720	10.91	(7.57, 14.25)	
2014	54	380 248	14.20	(10.41, 17.99)	
2015	25	384 777	6.50	(3.95, 9.04)	<.0001
Age					
< 1 year	221	598 314	36.94	(32.07, 41.81)	
1 year	172	599 350	28.70	(24.41, 32.99)	
2 years	100	608 079	16.45	(13.22, 19.67)	
3 years	64	613 521	10.43	(7.88, 12.99)	
4 years	51	607 200	8.40	(6.09, 10.70)	
5 years	44	617 521	7.13	(5.02, 9.23)	<.0001
Ethnicity					
Māori	272	961 663	28.30	(24.92, 31.65)	
Pacific	97	357 772	27.10	(21.72, 32.51)	
Asian	43	385 257	11.20	(7.83, 14.50)	
NZEO	240	2 240 982	10.70	(9.35, 12.06)	<.0001
NZ deprivation[d]					
Low	99	918 521	10.80	(8.66, 12.90)	
Medium	202	1 357 914	14.90	(12.82, 16.93)	
High	347	1 367 514	25.40	(22.7, 28.04)	<.0001
Geographic location[e]					
Northern	261	1 425 186	18.30	(16.09, 20.54)	
Midland	181	738 292	24.50	(20.94, 28.09)	
Central	98	709 137	13.80	(11.08, 16.56)	
South Island	108	771 243	14.00	(11.36, 16.64)	<.0001

Abbreviations: CI, confidence interval; NZ, New Zealand; NZEO, New Zealand European and Other.

[a]Person-years for 2006 and 2013 equate to the number of children less than 6 years of age counted during the 2006 and 2013 censuses, respectively; person-years for 2007–2012 and 2014–2015 were imputed by assuming the increase in the number of children between 2006 and 2013 was linear.

[b]Rate per 100 000 person-years.

[c]Cochran-Armitage test for trend or χ^2 test.

[d]NZDep13 levels collapsed into categories: Low (1–3); Medium (4–7); High (8–10).

[e]District Health Boards collapsed into geographic locations: Northern (Northland, Waitemata, Auckland, Counties Manukau); Midland (Waikato, Lakes, Bay of Plenty, Tairawhiti, Taranaki); Central (Hawke's Bay, MidCentral, Whanganui, Capital and Coast, Hutt, Wairarapa); South Island (Nelson Marlborough, West Coast, Canterbury, South Canterbury, Southern).

Ethnicity

The highest rates of initial IPD hospitalization were in Māori children (28.30, 95% confidence interval [CI]: 24.92, 31.65), followed by Pacific children (27.10, 95% CI: 21.72, 32.51) (Table 1). Among all ethnic groups, there was a statistically significant decrease in the rate of initial IPD hospitalization between 2006 and 2015 ($P < .05$) (Table 1). During the 10-year period, the rate of initial IPD hospitalization among Māori children less than 6 years of age decreased by 79%, compared to a 67% decrease

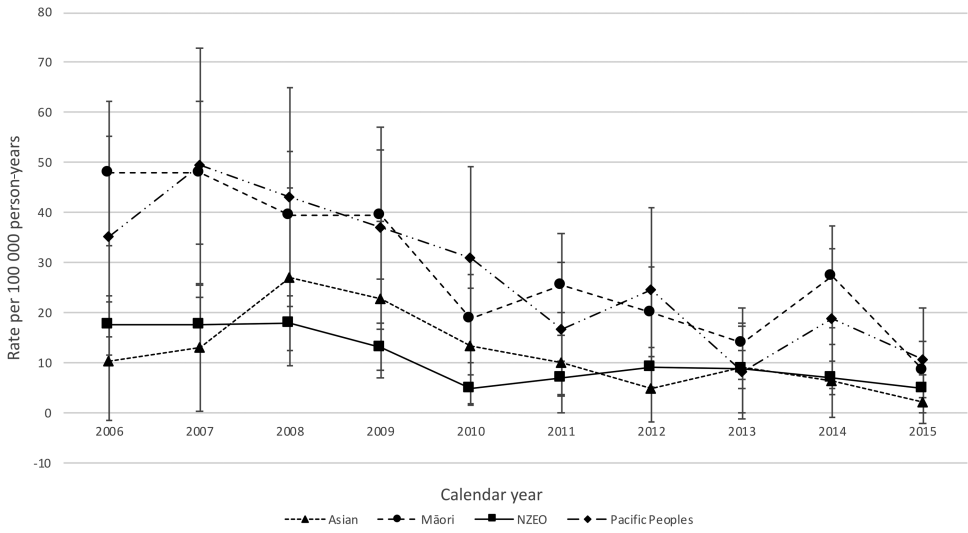

Figure 2. Rates with 95% confidence intervals of initial invasive pneumococcal disease hospitalization among children less than 6 years of age, by calendar year and ethnicity from 2006 to 2015 (inclusive). Abbreviation: NZEO, New Zealand European and Other.

in IPD hospitalization among all ethnicities between 2006 and 2013 (Figure 2).

Socioeconomic Deprivation

Children who lived in areas of higher socioeconomic deprivation had higher rates of initial hospitalizations for IPD (Table 1). However, the discrepancy lessened over time (Figure 3). During the 10-year period, the rate of hospitalization among children less than 6 years of age significantly decreased in all but the least deprived group (specifically deprivation groups 2 and 3) ($P < .05$).

All-cause Pneumonia

There were 26 589 children less than 6 years of age hospitalized for all-cause pneumonia between 2006 and 2015 (Table 2), 89% of whom had a single admission, 9% of whom had 2 admissions, and 2% of whom had between 3 and 12 admissions. Median age at first hospitalization was 18.4 months (IQR: 9.9, 34.5). During the 10-year period, there was a statistically significant decrease in the rate of initial all-cause pneumonia hospitalizations among children less than 6 years of age, from 976 per 100 000 person-years in 2006 to 801 per 100 000 person-years in 2015 ($P < .001$).

Ethnicity

The highest rates of initial all-cause pneumonia hospitalization were in Pacific children (2327, 95% CI: 2277, 2377), followed by Māori children (1030, 95% CI: 1010, 1050) (Table 2). Among all ethnic groups except Asian, there was a statistically significant decrease in the rate of initial all-cause pneumonia

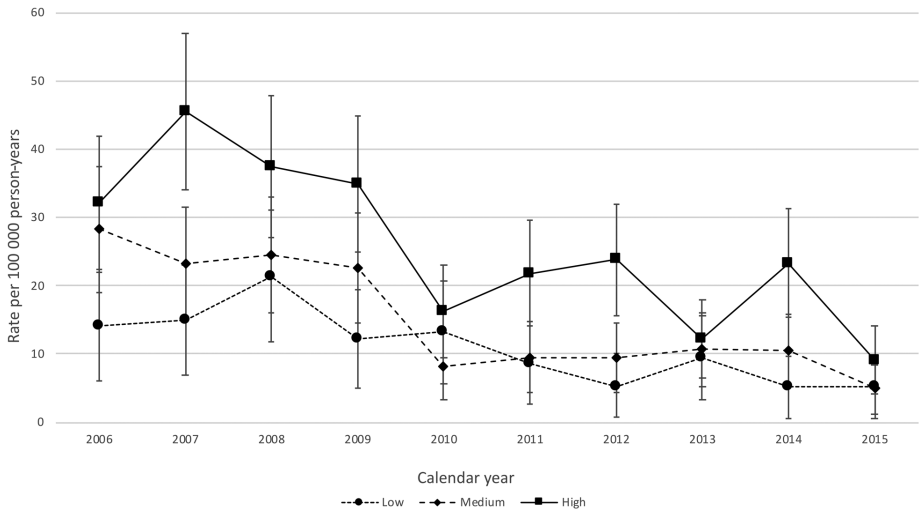

Figure 3. Rates with 95% confidence intervals of initial invasive pneumococcal disease hospitalization among children less than 6 years of age, by calendar year and deprivation from 2006 to 2015 (inclusive).

Table 2. Rates of Initial All-cause Pneumonia Hospitalizations Among Children Less Than 6 Years of Age From 2006 to 2015 (Inclusive)

	N	Person-Years[a]	Rate[b]	(95% CI)	*P*[c]
Calendar year					
2006	3359	344 020	976	(943, 1009)	
2007	3072	348 548	881	(850, 913)	
2008	3338	353 077	945	(913, 977)	
2009	3508	357 606	981	(949, 1013)	
2010	2902	362 135	801	(772, 831)	
2011	3065	366 663	836	(806, 866)	
2012	2873	371 192	774	(746, 802)	
2013	2649	375 720	705	(678, 732)	
2014	2780	380 248	731	(704, 758)	
2015	3083	384 777	801	(773, 830)	<.0001
Age					
< 1 year	10 251	598 314	1713	(1680, 1746)	
1 year	8959	599 350	1495	(1464, 1526)	
2 years	4611	608 079	758	(736, 780)	
3 years	3094	613 521	504	(487, 522)	
4 years	2133	607 200	351	(336, 366)	
5 years	1581	617 521	256	(243, 269)	<.0001
Ethnicity					
Māori	9904	961 663	1030	(1010, 1050)	
Pacific	8325	357 772	2327	(2277, 2377)	
Asian	2397	385 257	622	(597, 647)	
NZEO	9950	2 240 982	444	(435, 453)	<.0001
NZ deprivation[d]					
Low	4998	918 521	544	(529, 559)	
Medium	8983	1 357 914	662	(648, 675)	
High	16 483	1 367 514	1205	(1187, 1224)	<.0001
Geographic location[e]					
Northern	15 843	1 425 186	1112	(1094, 1129)	
Midland	5940	738 292	805	(784, 825)	
Central	5275	709 137	744	(724, 764)	
South Island	3408	771 243	442	(427, 457)	<.0001

Abbreviations: CI, confidence interval; NZ, New Zealand; NZEO, New Zealand European and Other.

[a]Person-years for 2006 and 2013 equate to the number of children less than 6 years of age counted during the 2006 and 2013 censuses, respectively; person-years for 2007–2012 and 2014–2015 were imputed by assuming the increase in the number of children between 2006 and 2013 was linear.

[b]Rate per 100 000 person-years.

[c]Cochran-Armitage test for trend or χ^2 test.

[d]NZDep13 levels collapsed into categories: Low (1–3); Medium (4–7); High (8–10).

[e]District Health Boards collapsed into geographic locations: Northern (Northland, Waitemata, Auckland, Counties Manukau); Midland (Waikato, Lakes, Bay of Plenty, Tairawhiti, Taranaki); Central (Hawke's Bay, MidCentral, Whanganui, Capital and Coast, Hutt, Wairarapa); South Island (Nelson Marlborough, West Coast, Canterbury, South Canterbury, Southern).

hospitalization between 2006 and 2015 ($P < .01$) (Figure 4). During the 10-year period, the rate of initial all-cause pneumonia hospitalization among Māori and Pacific children less than 6 years of age decreased by 12% and 21%, respectively.

Socioeconomic Deprivation

Children who lived in areas of higher socioeconomic deprivation had higher rates of initial hospitalizations for all-cause pneumonia (Table 2); the discrepancy has not lessened over time (Figure 5). During the 10-year period, the rate of hospitalization among children less than 6 years of age significantly decreased in all deprivation groups ($P < .05$).

Otitis Media

There were 44 545 hospitalizations for OM among children less than 6 years of age (Table 3), 78% of whom had a single admission, 16% of whom had 2 admissions, 4% of whom had 3 admissions, 1% of whom had 4 admissions, and less than 1% of whom had between 5 and 12 admissions. Median age at first hospitalization was 27.9 months (IQR: 16.6, 47.8). During the 10-year period, there was a statistically significant decrease in the rate of initial OM hospitalizations among children less than 6 years of age from 1783 per 100 000 person-years in 2006 to 1192 per 100 000 person-years in 2015 ($P < .001$).

Ethnicity

Rates of initial OM hospitalization were highest for Māori children (1862, 95% CI: 1834, 1889), followed by Pacific children (1708, 95% CI: 1665, 1751) (Table 3). Among all ethnic groups, there was a statistically significant decrease in the rate of initial OM hospitalization between 2006 and 2015 ($P < .001$) (Figure 6). During the 10-year period, the rate of initial OM hospitalization among Māori children less than 6 years of age decreased by 51%.

Socioeconomic Deprivation

Children who lived in areas of higher socioeconomic deprivation had higher rates of initial hospitalizations for OM (Table 3); however, the discrepancy lessened over time (Figure 7). During the 10-year period, the rate of hospitalization among children less than 6 years of age significantly decreased in all deprivation groups ($P < .001$).

DISCUSSION

As with all countries that have introduced a PCV program [11], New Zealand has experienced a dramatic decline in the rate of initial IPD hospitalizations in the population eligible for PCV vaccination. This decline has continued over time throughout all the vaccine periods since the introduction of the childhood program in 2008. Our study shows that although the highest rates of IPD hospitalizations were in indigenous (Māori) children, followed by those who identify as Pacific Island, the rates in these 2 groups decreased disproportionately compared with other ethnic groups. This has resulted in an overall reduction in ethnic disparities for this disease over time. We did not observe significant reductions among Asians; however, this group had very low rates at baseline with small relative gains from the immunization program. We also know that in New Zealand this group has active health seeking behaviour [12]. Reductions in socioeconomic disparities were also shown over this period due to greater reductions for those from higher socioeconomic deprivation.

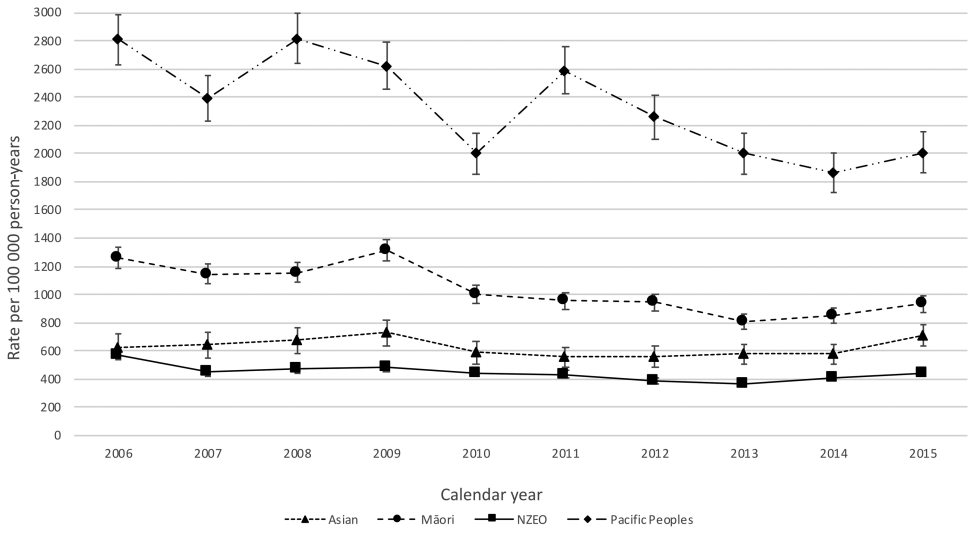

Figure 4. Rates with 95% confidence intervals of initial all-cause pneumonia hospitalization among children less than 6 years of age, by calendar year and ethnicity from 2006 to 2015 (inclusive). Abbreviation: NZEO, New Zealand European and Other.

Reductions in Pneumonia and Otitis Media

Alongside IPD reduction, our study showed decreases in all-cause pneumonia and OM. Reductions in socioeconomic disparities were also observed for OM, with greater disease reductions seen in children from lower socioeconomic groups; this trend was not shown for all-cause pneumonia. Reductions in pneumonia and OM have been reported from both clinical trials [13, 14] and observational studies [15–21]. Although a positive impact on pneumonia is consistently observed, the impact on OM has been more variable, possibly due to variation in local OM etiology, case ascertainment, and definitions and differences in standards of care [21, 22]. The peak incidence of OM in the current NZ study population occurred from 1 to 2 years of age, which is consistent with some recent studies of OM [23] but slightly older than the age of peak incidence reported by Teele et al and in other prospective studies of AOM [24, 25]. In this study population, the incidence of OM was lowest among Asians. In New Zealand, Asians are generally in higher socioeconomic groups and have better health on a range of health indicators compared to other ethnic groups [26], possibly due to a "healthy migrant effect" [27]. Further, the relationship between race/ethnicity and OM may be confounded

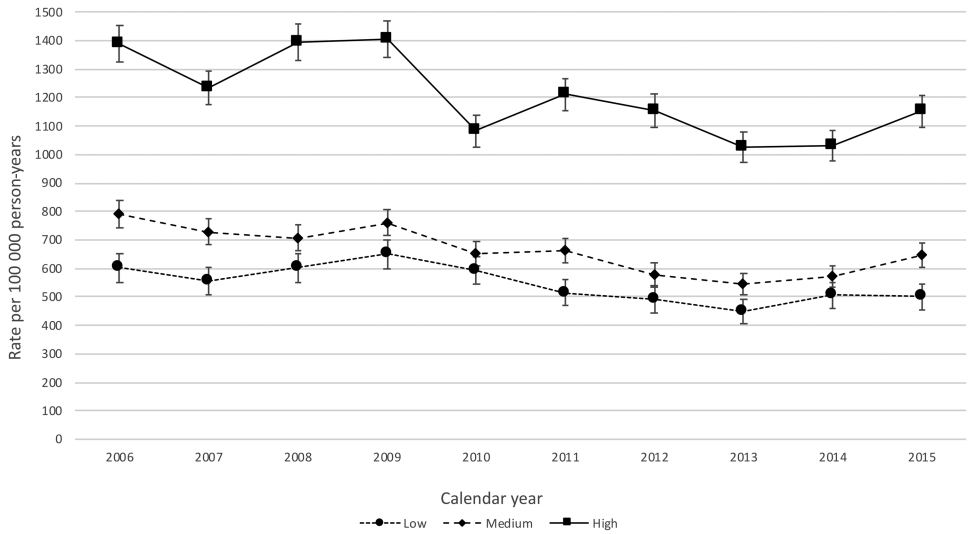

Figure 5. Rates with 95% confidence intervals of initial all-cause pneumonia hospitalization among children less than 6 years of age, by calendar year and deprivation from 2006 to 2015 (inclusive).

Table 3. Rates of Initial Otitis Media Hospitalizations Among Children Less Than 6 Years of Age From 2006 to 2015 (Inclusive)

	N	Person-Years[a]	Rate[b]	(95% CI)	*P*[c]
Calendar year					
2006	6133	344 020	1783	(1738, 1827)	
2007	6444	348 548	1849	(1804, 1894)	
2008	6555	353 077	1857	(1812, 1901)	
2009	7124	357 605	1992	(1946, 2038)	
2010	5907	362 135	1631	(1590, 1673)	
2011	6027	366 663	1644	(1602, 1685)	
2012	5923	371 192	1596	(1555, 1636)	
2013	4895	375 720	1303	(1266, 1339)	
2014	4560	380 248	1199	(1164, 1234)	
2015	4586	384 777	1192	(1157, 1226)	<.001
Age					
< 1 year	8314	598 314	1390	(1360, 1419)	
1 year	16 964	599 350	2830	(2788, 2873)	
2 years	11 002	608 079	1809	(1776, 1843)	
3 years	8027	613 521	1308	(1280, 1337)	
4 years	8006	607 200	1319	(1290, 1347)	
5 years	5841	617 521	946	(922, 970)	
Ethnicity					
Māori	17 902	961 663	1862	(1834, 1889)	
Pacific	6111	357 772	1708	(1666, 1751)	
Asian	2356	385 257	612	(587, 636)	
NZEO	31 625	2 240 982	1411	(1396, 1427)	<.0001
NZ deprivation[d]					
Low	12 256	918 521	1334	(1311, 1358)	
Medium	21 231	1 357 914	1564	(1542, 1585)	
High	24 436	1 367 514	1787	(1765, 1809)	<.0001
Geographic location[e]					
Northern	20 212	1 425 186	1418	(1399, 1438)	
Midland	14 615	738 292	1980	(1947, 2012)	
Central	9169	709 137	1293	(1267, 1319)	
South Island	13 931	771 243	1806	(1776, 1836)	<.0001

Abbreviations: CI, confidence interval; NZ, New Zealand; NZEO, New Zealand European and Other.

[a]Person-years for 2006 and 2013 equate to the number of children less than 6 years of age counted during the 2006 and 2013 censuses, respectively; person-years for 2007–2012 and 2014–2015 were imputed by assuming the increase in the number of children between 2006 and 2013 was linear.

[b]Rate per 100 000 person-years.

[c]Cochran-Armitage test for trend or χ^2 test

[d]NZDep13 levels collapsed into categories: Low (1–3); Medium (4–7); High (8–10).

[e]District Health Boards collapsed into geographic locations: Northern (Northland, Waitemata, Auckland, Counties Manukau); Midland (Waikato, Lakes, Bay of Plenty, Tairawhiti, Taranaki); Central (Hawke's Bay, MidCentral, Whanganui, Capital and Coast, Hutt, Wairarapa); South Island (Nelson Marlborough, West Coast, Canterbury, South Canterbury, Southern).

by various social factors, including maternal marital status, household size, breastfeeding, and maternal age [28]. However, in New Zealand, Pacific and Maori have the highest burden of many infectious diseases; one of the major underlying contributing factors is poor housing and overcrowding [29, 30]. They also have a higher rate (25%) of bacterial OM (with effusion by 2 years of age) than other populations [31]. This could explain why we see a young median age for this outcome in New Zealand.

Israel has implemented a prospective-based surveillance of OM episodes with one study reporting near-elimination of pneumococcal-related OM following the introduction and high uptake of PCV [32]. However, another study in Israel reported pneumococcal-associated OM complications declined, but OM remained a significant cause of hospitalization [33]. In a retrospective study of AOM episodes in Israeli children less than 6 years of age, isolation of *Streptococcus pneumoniae* was significantly higher in PCV-unimmunized children (69%) than PCV7 immunized (59%), and PCV13-immunized (50%) [34]. So although PCV appears to decrease pneumococcal-associated OM, the absolute rates vary. Reductions of the PCV-types provide a mechanism for our observed reductions.

Sociodemographic Differences

Reductions in racial and ethnic disparities in disease incidence following PCV vaccination have been observed previously. A systematic review of the impact of PCV on ethnic and socioeconomic disparities found 17 studies (16 from North America and 1 from Australia) evaluating IPD in this context. One further study from Australia evaluated pneumonia as an outcome. The conclusion from the review was that children under 2 years of age in resource-poor populations appeared to benefit most from the introduction of PCV [7]. Similarly, in New Zealand the implementation of a mass meningococcal group B vaccination campaign between 2004 and 2006 was associated with a reduction in ethnic disparities for meningococcal disease hospital admissions [35].

In Israel, a prospective pneumococcal carriage study observed declines in carriage of vaccine types following PCV7 then PCV13, associated with a significant increase in non-vaccine types. Higher carriage rates were observed in Bedouin children compared with Jewish children, and although little reduction in carriage was observed after PCV7 introduction, PCV13 introduction resulted in a significant reduction in the Bedouin population but not the Jewish population. The authors suggested a faster achievement of herd immunity in the more overcrowded Bedouin population [4]. This is also a potential explanation for the NZ observation of higher reductions for Pacific people who tend to live in larger households, are more at risk for overcrowded living conditions, and also have high vaccine uptake (>95%). Also, carriage in these communities is likely to be higher and from an early age; therefore, it is possible they are primed prior to completing the primary course of pneumococcal vaccines [36].Similar observations have occurred in the United States where ecological studies indicate a larger decrease in vaccine serotype IPD in black children compared to white children [5] but not in the indigenous American populations [6].

Study Limitations

This study utilized data for the entire birth cohorts for New Zealand over a period of 10 years. There were very little missing data. Ethnicity and the measure of socioeconomic deprivation

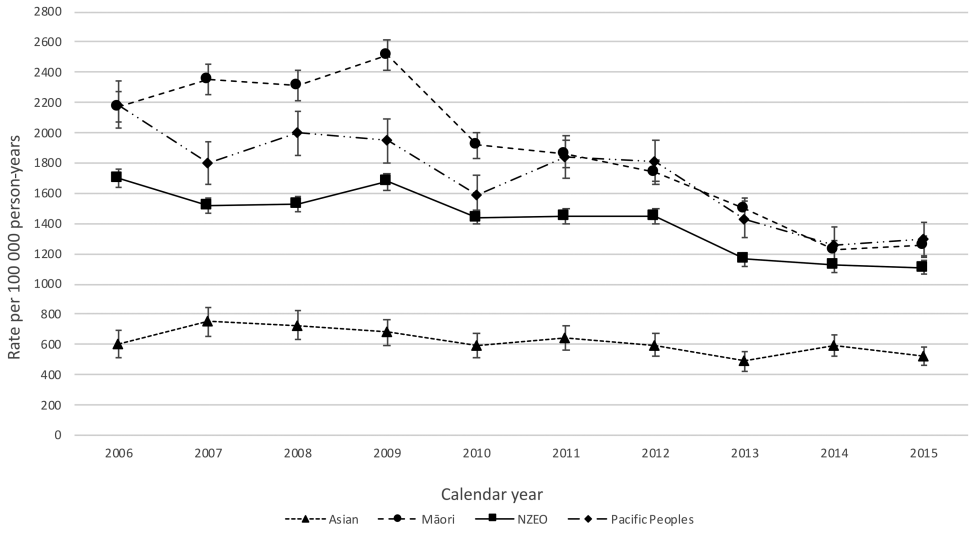

Figure 6. Rates with 95% confidence intervals of initial otitis media hospitalization among children less than 6 years of age, by calendar year and ethnicity from 2006 to 2015 (inclusive). Abbreviation: NZEO, New Zealand European and Other.

are robust. However, there are limitations. Establishing an accurate denominator is challenging, with limitations associated with the use of census data and the assumption of a linear increase in population between census years. This vaccine impact analysis is based on calendar time of vaccine introduction. As such, we are not examining vaccine effectiveness directly but are looking at a mixture of direct and indirect effects of PCV vaccination at a population level, as well as unmeasured changes in health-seeking behaviours, diagnostic criteria, treatment guidelines, and other unmeasured variables. In addition, a major limitation of the current study is that only a short period had elapsed since PCV13 was introduced (2014) and the end of the study period (2015). As pneumococcal infection did not become notifiable until 2008 and notifications are dependent on the reporting behavior of laboratories, there are few conclusions that can be made from notification data with respect to infection incidence. However, we used hospitalization codes for our study, which we believe should be a relatively consistent measure of pneumococcal infection during the study. Moreover, our definition was deliberately broad in order to capture "clinically suspected" cases. Other factors that may influence the incidence rates over time include health policy changes (eg, access to publicly funded healthcare), the interplay between ethnicity and socioeconomic status, issues around poverty including household overcrowding, and changes to national immunisation coverage.

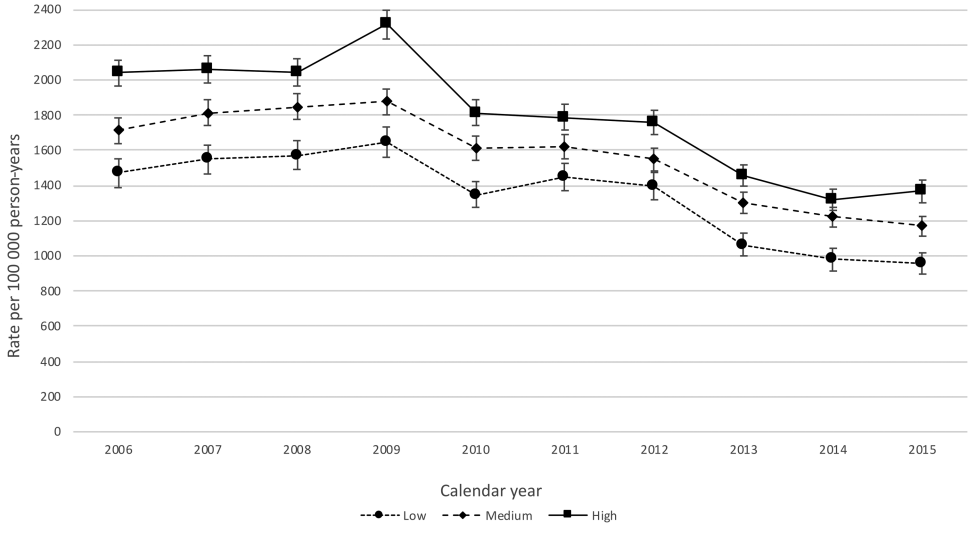

Figure 7. Rates with 95% confidence intervals of initial otitis media hospitalization among children less than 6 years of age, by calendar year and deprivation from 2006 to 2015 (inclusive).

CONCLUSIONS

Overall, although there have been general increases in infectious disease rates including respiratory infections in New Zealand [1], all-cause pneumonia has declined [37]. Although ethnic and socioeconomic disparities associated with IPD have been previously reported, this study also examined pneumonia and OM, which are less well described in terms of disparities. At a time when other infectious diseases have been trending upward in New Zealand, the PCV program has been associated with a significant decline in IPD, pneumonia, and OM-associated hospitalization. The use of PCV in New Zealand has been associated with significant reductions in disparities in hospitalization for IPD, pneumonia, and OM, as well as in ethnic and socioeconomic disparities in hospitalization for IPD and OM.

Notes

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